

Appendix 8. Aquifer Recharge Calculations

To determine risk associated with aquifer recharge of treated effluent, the fate and transport of representative stressors were conducted for a range of required setbacks of 200, 500 and 2,640 feet (0.5 mile). Utilizing hydrologic data for the Surficial Aquifer, the fate and transport of the selected representative stressors can be estimated.

The time of travel to the horizontal setback distances (X) can be estimated by dividing the setback distances by the seepage velocity (v_s) (Eqn. 28). Seepage velocity is defined as the velocity representing the average rate at which ground water moves (Fetter, 1994) and is estimated by dividing the Darcy flow (q) by the porosity (n) of the hydrologic unit (Eqn. 29). Porosity represents the ratio between the volumes of voids over the total volume of the media (Freeze and Cherry, 1979). In this analysis, published porosity values were used. Darcy flow is defined as fluid flow through porous media (e.g. sand) (Freeze and Cherry; 1979), taking into consideration that ground water flows through porous media, Darcian assumptions must be applied. Darcy flow takes into account horizontal hydraulic conductivity (K_h) and the horizontal hydraulic gradient (i) (Eqn. 30). Hydraulic conductivity represents the ability of the media to transmit water (Fetter, 1994). Simple substitution of the seepage velocity and Darcy flow equations into Equation 28 will result in Equation 31.

$$t = \frac{X}{v_s} \quad (\text{Eqn. 28})$$

$$v_s = \frac{q}{n} \quad (\text{Eqn. 29})^1$$

$$q = K_h \times i \quad (\text{Eqn. 30})^2$$

$$t = \frac{Xn}{K_h i} \quad (\text{Eqn. 31})$$

Once the time of travel to the predetermined setback distances (Appendix Table 8-1) has been estimated, a fate and transport analysis can be used to determine the final concentrations of representative stressors. The fate and transport of representative stressors can be estimated by a first order decay model (Eqn. 32), which estimates the final concentration (C) of the representative stressors in correlation to vertical travel times estimated earlier. This first order decay model is appropriate for analysis of the organic constituents, because it takes into account natural attenuation processes such as biodegradation, hydrolysis and sorption (Suthersan, 2002).

$$C = C_o e^{-kt_c} \quad (\text{Eqn. 32})^3$$

¹ Same equation used in Appendix 4 and 5 (Eqn. 4 and Eqn. 14)

² Same equation used in Appendix 5 (Eqn. 15)

³ Same equation used in Appendix 7 (Eqn. 20)

where:

C	= Final concentration of stressors
C_o	= Initial concentration of stressors
k	= Decay coefficient of stressors
t_C	= Travel time of stressors

Half-life ($t_{1/2}$) is defined as the time it takes for stressors to reach half of the initial concentration. The decay coefficient (k) can be determined by rearranging Equation 32, substituting the half-life in place of the travel time of stressors (t_C) and equating the ratio of the final versus initial concentrations to 0.5 (Eqn. 33). The decay coefficient (Eqn. 34) is simplified by rearranging Equation 33. Published values for half-life are available and were identified for the selected representative stressors (Howard et al., 1991).

$$\frac{C}{C_o} = 0.5 = e^{-kt_{1/2}} \quad (\text{Eqn. 33})^3$$

$$k = \frac{0.693}{t_{1/2}} \quad (\text{Eqn. 34})^3$$

The travel time of representative stressors (t_C) are determined by multiplying the retardation coefficient (R) by the effluent travel time (t_E) (Eqn. 35). In this analysis, the effluent travel time is equivalent to the vertical travel time estimated earlier.

$$t_C = R \times t_E \quad (\text{Eqn. 35})^3$$

The retardation coefficient takes into account sorption, a natural attenuation process which increases the travel time of stressors. The greater the travel time of stressors, the more time there is for other natural attenuation process to occur, such as biodegradation and hydrolysis. Biodegradation results in the degradation of organic material and may also mediate transformations in the state of inorganic material, resulting in decreasing concentrations over time. Hydrolysis is the process whereby organic and inorganic solutes react with water resulting in degradation and transformation (Suthersan, 2002). Calculation for the retardation coefficient, for dissolved organic constituents, is shown below in Equation 36 (Suthersan, 2002).

$$R = 1 + \frac{\rho_b K_d}{n} \quad (\text{Eqn. 36})^3$$

where:

ρ_b	= Bulk density = $\rho_s(1-n)$	(Eqn. 37) ³
ρ_s	= soil density	
n	= porosity	
K_d	= Distribution coefficient = $K_{oc}f_{oc}$	(Eqn. 38) ³
K_{oc}	= Sorption coefficient	

³ Same equation used in Appendix 7 (Eqn. 21 to Eqn. 26)

f_{oc} = fraction of total organic carbon

$$R = 1 + \frac{\rho_s(1-n)K_{oc}f_{oc}}{n} \quad (\text{Eqn. 39})^3$$

Sorption coefficients (K_{oc}) were obtained from published values for each representative stressor (Montgomery, 2000). For purposes of risk assessment, conservative values (indicating the least sorption) were selected to calculate the distribution coefficient and therefore the retardation coefficient. Ultimately, this produces conservative estimates of stressor concentrations at the receptors, since the data used relate to the lowest reasonably expected retardation and the shortest travel time. The calculations incorporated a typical value for sediment density of 2.63 g/cm³ (Freeze and Cherry, 1979). Weighted mean porosity values (Appendix 3), based on unit thickness, were used in the calculations.

Appendix Table 8-2 to 8-4 summarizes the fate and transport of the representative stressors within 200, 500 and 2640 feet (0.5 mile) from the facility in Dade, Pinellas and Brevard Counties.

³ Same equation used in Appendix 7 (Eqn. 27)

Appendix Table 8-1. Fate Transport (200')

		Dade County											
Surrogate	Published Half-Life in Groundwater ($t_{1/2}$) (days)	Published Sorption Coefficient (K_{oc})	Fraction of Total Organic Carbon (f_{oc})	Distribution Coefficient (K_d)	Soil Density (ρ_s)	Porosity (n)	Bulk Density (ρ_b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t_E) (years)	Contaminant Travel Time (t_C) (years)	Decay Coefficient (k) (day $^{-1}$)	Concentration at Injection Pt. (C_0)	Concentration at Supply Well (C)
	Max	Max	0.01	0.014	2.63	0.33	1.76	1.08	0.11	0	0.0004	7.18	7.06
Chloroform ($\mu\text{g/L}$)	1800	1.44	0.01	0.023	2.63	0.33	1.76	1.12	0.11	0	0.0010	4.66	4.46
Tetrachloroethylene (PCE) ($\mu\text{g/L}$)	720	2.25	0.01	0.047	2.63	0.33	1.76	1.25	0.11	0	0.0003	0.010	0.01
Chlordane ($\mu\text{g/L}$)	2772	4.72	0.01	0.027	2.63	0.33	1.76	1.15	0.11	0	0.0018	5.00	0.010
Arsenic (mg/L)	N/A	2.73	0.01	0.045	2.63	0.33	1.76	1.24	0.11	0	N/A	4.57	0.5
Di(2-ethylhexyl) Phthalate (DEHP) ($\mu\text{g/L}$)	389	4.48	0.01	0.005	2.63	0.33	1.76	1.03	0.11	0.1	N/A	8.75	8.75
Ammonia (mg/L) (conservative behavior)	N/A	0.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.64	0.64
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

		Pinellas County											
Surrogate	Published Half-Life in Groundwater ($t_{1/2}$) (days)	Published Sorption Coefficient (K_{oc})	Fraction of Total Organic Carbon (f_{oc})	Distribution Coefficient (K_d)	Soil Density (ρ_s)	Porosity (n)	Bulk Density (ρ_b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t_E) (years)	Contaminant Travel Time (t_C) (years)	Decay Coefficient (k) (day $^{-1}$)	Concentration at Injection Pt. (C_0)	Concentration at Supply Well (C)
	Max	Max	0.01	0.014	2.63	0.25	1.97	1.11	0.11	0.58	0.0004	6.70	6.70
Chloroform ($\mu\text{g/L}$)	1800	1.44	0.01	0.023	2.63	0.25	1.97	1.18	0.86	6.9	0.0010	2.50	0.22
Tetrachloroethylene (PCE) ($\mu\text{g/L}$)	720	2.25	0.01	0.026	2.63	0.25	1.97	1.20	0.86	7.0	0.0002	1.74	1.14
Hexachlorobenzene ($\mu\text{g/L}$)	4178	2.56	0.01	0.028	2.63	0.25	1.97	1.22	0.86	7.1	0.0005	1.28	0.39
Pentachlorophenol ($\mu\text{g/L}$)	1520	2.76	0.01	0.060	2.63	0.25	1.97	1.47	0.86	8.6	0.0007	1.82	0.23
Benz(a)pyrene ($\mu\text{g/L}$)	1060	5.95	0.01	0.047	2.63	0.25	1.97	1.37	1.22	8.0	0.0003	0.640	0.31
Chlordane ($\mu\text{g/L}$)	2772	4.72	0.01	0.027	2.63	0.25	1.97	1.22	0.86	7.12	N/A	0.003	0.003
Arsenic (mg/L)	N/A	2.73	0.01	0.045	2.63	0.25	1.97	1.35	0.86	7.9	0.0018	1.25	0.01
Di(2-ethylhexyl) Phthalate (DEHP) ($\mu\text{g/L}$)	389	4.48	0.01	0.005	2.63	0.25	1.97	1.04	0.86	6.1	N/A	18.00	18.00
Ammonia (mg/L) (conservative behavior)	N/A	0.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28	0.28
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

		Brevard County												
Surrogate	Published Half-Life in Groundwater ($t_{1/2}$) (days)	Published Sorption Coefficient (K_{oc})	Fraction of Total Organic Carbon (f_{oc})	Distribution Coefficient (K_d)	Soil Density (ρ_s)	Porosity (n)	Bulk Density (ρ_b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t_E) (years)	Contaminant Travel Time (t_C) (years)	Decay Coefficient (k) (day $^{-1}$)	Concentration at Injection Pt. (C_0)	Concentration at Supply Well (C)	
	Max	Max	0.01	0.014	2.63	0.36	1.68	1.07	0.11	3.03	3	0.0004	230	146
Chloroform ($\mu\text{g/L}$)	1800	1.44	0.01	0.023	2.63	0.36	1.68	1.11	3.03	3	0.0010	1.00	0.3	
Tetrachloroethylene (PCE) ($\mu\text{g/L}$)	720	2.25	0.01	0.047	2.63	0.36	1.68	1.22	3.03	4	0.0003	0.010	0.0	
Chlordane ($\mu\text{g/L}$)	2772	4.72	0.01	0.027	2.63	0.36	1.68	1.13	3.03	3	N/A	0.005	0.005	
Arsenic (mg/L)	N/A	2.73	0.01	0.045	2.63	0.36	1.68	1.21	3.03	4	0.0018	5.00	0.5	
Di(2-ethylhexyl) Phthalate (DEHP) ($\mu\text{g/L}$)	389	4.48	0.01	0.005	2.63	0.36	1.68	1.02	3.03	3	N/A	8.75	8.75	
Ammonia (mg/L) (conservative behavior)	N/A	0.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.60	9.60	
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

N/A = not applicable

Appendix Table 8-2. Fate Transport (500')

		Dade County						Pinellas County					
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)	Contaminant Travel Time (t _c) (years)	Decay Coefficient (k) (day ⁻¹)	Concentration at Injection Pt. (C ₀)	Concentration at Supply Well (C)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.33	1.76	1.98	0.28	0	0.0004	7.18	6.88
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.33	1.76	1.12	0.28	0	0.0010	4.66	4.17
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.33	1.76	1.25	0.28	0	0.0003	0.010	0.01
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.33	1.76	1.15	0.28	0	N/A	0.010	0.010
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.33	1.76	1.24	0.28	0	0.0018	5.00	3.99
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.33	1.76	1.03	0.28	0.3	N/A	8.75	8.75
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.64	0.64

(Appendix 8 continued)

		Dade County						Pinellas County					
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)	Contaminant Travel Time (t _c) (years)	Decay Coefficient (k) (day ⁻¹)	Concentration at Injection Pt. (C ₀)	Concentration at Supply Well (C)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.25	1.97	1.11	1.64	16.3	0.0004	6.70	6.68
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.25	1.97	1.18	1.64	17.2	0.0010	2.50	0.01
Hexachlorobenzene (µg/L)	4178	2.56	0.01	0.026	2.63	0.25	1.97	1.20	1.64	17.6	0.0002	1.74	0.60
Pentachlorophenol (µg/L)	1520	2.76	0.01	0.028	2.63	0.25	1.97	1.22	1.64	17.8	0.0005	1.28	0.07
Benz(a)pyrene (µg/L)	1060	5.95	0.01	0.060	2.63	0.25	1.97	1.47	1.64	21.5	0.0007	1.82	0.01
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.25	1.97	1.37	1.64	20.1	0.0003	0.640	0.10
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.25	1.97	1.22	1.64	17.80	0.003	0.003	0.003
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.25	1.97	1.35	1.64	19.8	0.0018	1.25	1.25
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.25	1.97	1.04	1.64	15.2	N/A	18.00	18.00
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28	0.28

		Dade County						Brevard County					
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)	Contaminant Travel Time (t _c) (years)	Decay Coefficient (k) (day ⁻¹)	Concentration at Injection Pt. (C ₀)	Concentration at Supply Well (C)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.36	1.68	1.07	1.58	8	0.0004	230	230
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.36	1.68	1.11	1.58	8	0.0010	1.00	0.1
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.36	1.68	1.22	1.58	9	0.0003	0.010	0.0
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.36	1.68	1.13	1.58	9	0.005	0.005	0.005
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.36	1.68	1.21	1.58	9	0.0018	5.00	0.0
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.36	1.68	1.02	1.58	8	N/A	8.75	8.75
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.60	9.60

N/A = not applicable

Appendix Table 8-3. Fate Transport (0.5 mile)

Dade County									
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.33	1.76	1.08	1.47
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.33	1.76	1.12	2
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.33	1.76	1.25	2
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.33	1.76	1.15	N/A
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.33	1.76	1.24	2
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.33	1.76	1.03	2
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Pinellas County									
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.25	1.97	1.11	7.32
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.25	1.97	1.18	77.32
Hexachlorobutene (µg/L)	4178	2.56	0.01	0.026	2.63	0.25	1.97	1.20	91.0
Pentachlorophenol (µg/L)	1520	2.76	0.01	0.028	2.63	0.25	1.97	1.22	92.9
Benzo(a)pyrene (µg/L)	1060	5.95	0.01	0.060	2.63	0.25	1.97	1.47	94.2
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.25	1.97	1.37	113.6
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.25	1.97	1.22	106.1
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.25	1.97	1.35	77.32
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.25	1.97	1.04	104.6
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	80.3

Brevard County									
Surrogate	Published Half-Life in Groundwater (t _{1/2}) (days)	Published Sorption Coefficient (K _{oc})	Fraction of Total Organic Carbon (f _{oc})	Distribution Coefficient (K _d)	Soil Density (ρ _s)	Porosity (n)	Bulk Density (ρ _b)	Retardation Coefficient (R)	Effluent Travel Time to Receptor Wells (t _e) (years)
Chloroform (µg/L)	1800	1.44	0.01	0.014	2.63	0.36	1.68	1.07	4.04
Tetrachloroethylene (PCE) (µg/L)	720	2.25	0.01	0.023	2.63	0.36	1.68	1.11	40.04
Chlordane (µg/L)	2772	4.72	0.01	0.047	2.63	0.36	1.68	1.22	40.04
Arsenic (mg/L)	N/A	2.73	0.01	0.027	2.63	0.36	1.68	1.13	45
Di(2-ethylhexyl) Phthalate (DEHP) (µg/L)	389	4.48	0.01	0.045	2.63	0.36	1.68	1.21	40.04
Ammonia (mg/L) (conservative behavior)	N/A	0.49	0.01	0.005	2.63	0.36	1.68	1.02	40.04
Nitrates (mg/L) (conservative behavior)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A = not applicable